# Human Aspects for a Mission to an Asteroid

Clément Labbe, Jona Sandgren, Romain Mabboux, Roxane Josses, Shota Iwasaki

Double Degree and MSc students, KTH, Royal Institute of Technology, Stockholm, Sweden

***Abstract*—Because of their promising mineral resources, asteroids are gaining an increasing interest from private companies. This paper aims to present the background, the challenges and a proposal for a manned mission of mining towards an asteroid nearly orbiting Earth. A spotlight on human aspects will be given for the purpose of justifying the mission's choices, such as the atmosphere and water closed loops.**

**Index terms: Human, life, systems, psychology.**

## I. Introduction

### A. Backgroud

It is known that many asteroids exist in relative close proximity to Earth and that some might have valuable resources. It is therefore reasonable to assume that asteroid mining will be a commercial business in the future. 2016H03, also known as 469219 Kamooalewa, is one such asteroid with a size on the scale of 100 meters. This particular asteroid has a distance to Earth which is approximately 40 to 100 times the distance to the Moon and its orbit makes it a quasi−satellite of Earth. This means it orbits the Sun in such a way that it orbits the Earth. It is assumed that an exploration mission to the asteroid has already been done and found an abundance of precious resources. It is deemed feasible to setting up a mining operation and bringing the resources to Earth would be profitable. However, in order to set up the autonomous operation it seems necessary to send humans to the asteroid. This is a challenge since no such deep space mission has ever been done with humans on board.

### B. Task

The work on the mission was divided into four groups within a team, called the Blue team, and these were: Overall Coordination, Logistics and mission, Space Vehicle and Human aspects. In this report only the human aspects of the mission are considered. This meant that given a time frame that was negotiated with the other groups, all systems to support humans would have to be considered. This also included considering safety, redundancy and emergency scenarios. Final mass and volume requirements needed to be found so that the space vehicle could be designed. To collaborate successfully with the other groups was a necessary part to complete the project which is why it was also an objective.

## II. Mission requirements and assumptions

The design of a space mission becomes significantly more complicated when manned flights are considered. Therefore it was important to determine the specific requirements for the human aspects of the mission. The top-level requirements were :

- Provide life support systems (LSS) for a 3 members crew and a 330 days mission duration.
- Mission ready for launch in 2030.
- Use a launcher not too rough for the human body.
- Perform the entire mission assuming no resupply from Earth.
- Operate during all mission phases : launch, transit, asteroid parking, reentry.
- Provide 2 levels of redundancy.
- Enable extra-vehicular activities (EVA) for all crew members.
- Assess radiation dose seen by crew.
- Maximize reliability, maintainability and safety of LSS.

As the scope of the project has to be limited and largely conceptual, some approximations have been made regarding the way in which the human aspects have been dealt with:

- For launch and reentry phases, the Crew Dragon capsule was assumed to have its own LSS.
- Reasonable extrapolation of current technologies have been done, a technology readiness level (TRL) 5 was the low limit.
- The basic human needs were based on Table I.

Table I
BASIC HUMAN NEEDS

| Needs | Mass, kg per crew-member per day |
|---|---|
| Oxygen | 0.84 |
| Drinking water | 1.38 |
| Food preparation water | 1 |
| Urine flush water | 0.5 |
| Wash water | 1.29 |
| Food (partially dehydrated) | 2 |

## III. Limiting factors

For this mission, which is long but not as long as a Mars mission, it was proposed that mainly two factors were limiting from a human aspects perspective.

### A. *Radiation*

Radiation is one of the main factor which makes long space journeys so difficult. In Low Earth Orbit (LEO), the International Space Station (ISS) is considerably protected by the Earth magnetic field and allow the astronauts to stay up to one year without exposing them to a too high radiation dose. Regarding deep-space missions, the future astronauts will only be protected from radiation through the spacecraft and/or their spacesuits.

Radiation effects on the human body can be measured in different ways. For this study, the equivalent dose has been considered and it represents the absorbed dose to an organ, adjusted to account for the effectiveness of the type of radiation. Equivalent dose is calculated for individual organs. and is expressed in millisieverts (mSv) to an organ. The NASA limit for radiation exposure in LEO is 0.50 mSv/year [26]. Figure 1 shows the equivalent dose career limits set by NASA.

| Career Exposure Limits for NASA Astronauts by Age and Gender* | | | | |
|---|---|---|---|---|
| Age (years) | 25 | 35 | 45 | 55 |
| Male | 1.50 Sv | 2.50 Sv | 3.25 Sv | 4.00 Sv |
| Female | 1.00 Sv | 1.75 Sv | 2.50 Sv | 3.00 Sv |

Figure 1. Career Exposure Limits for NASA Astronauts by Age and Gender [26]

NASA estimates that during a 6-month journey to Mars, the astronauts will receive around 300 mSv [26]. On another hand, estimates for deep-space journeys suggest that the astronauts will be exposed to roughly 1-2 mSv/day [9]. Considering the worst case scenario, 2 mSv/day, a 333 day mission would expose the astronauts to a total of 660 mSv.

Experiences realized on-board the Mir station have shown that EVAs expose the astronauts at more than five times greater doses of radiation. For this reason, with an upper margin for an EVA of 8 hours the exposure could be 5 mSv. Considering a two-week duration of operations on the asteroid with one EVA per day, one can estimate the radiation dose received during the EVAs to 70 mSv.

The total dose received during the entire journey should then not exceed 750mSv. According to Figure 1 and considering the "worst" case, which corresponds to a 25-year female, the total radiation dose received during the expedition is below NASA's career limits. However the limit exposure for a year will be overtaken. This problem could be solved by the use of a daily suit described in subsection V-G.

### B. *Volume*

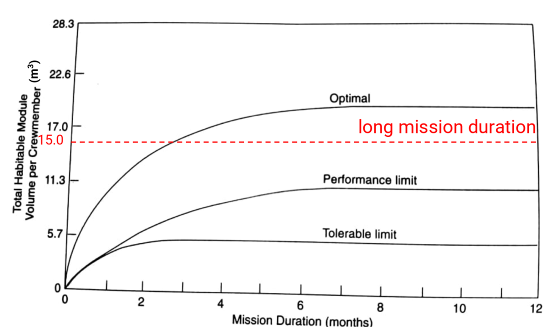



Figure 2. Affect of mission length on required habitable volume per crew member [9]

The habitable volume of a spacecraft is also a limiting factor, especially for longer missions. Figure 2 shows some different trend lines that came of

NASA's standard technical design 3000, or NASA-STD-3000, seen in literature [9]. It was decided that just scaling a space station volume would not be good enough. This was based on not being able to find any relation between space station size and mission success. Figure 2 shows the volumes that crew members have successfully carried out missions in for varying duration. It does not reflect psychological or physical stresses on the crew but in order to complete the mission the values shown should suffice. The level picked out from the graph was 15 $m^3$. This followed the recommendation to stay between the optimal and performance limit that was given in literature [9]. The reason that the chosen value is slightly above the midpoint of the lines is to make the crew as comfortable as possible while still keeping the volume within reason for the spacecraft. This was done to reduce both psychological or physical stress for the relatively long mission, even though there is no measure of how much. For comparison this volume reflects a medium sized bathroom with a toilet, bathtub, washing machine, sink and some cupboards. It is important to note that the volume chosen is a hard lower limit but the upper limit is not yet determined. This is because during the design it was important to get values to the people designing the space vehicle fast and a 10% margin was therefore added on the initial estimates to account for errors that would later be fixed. Since this margin is not likely to be hit, at least completely, there will be added space for the astronauts. This is seen at the end of the report when the final required volume is determined and how it differs from the estimate with margin.

## IV. OPEN-LOOP

When designing a Life Support System, it is important to first decide whether the system will be open-loop or partially closed-loop. The duration of this mission is 330 days, which is shorter than a Mars mission, where a complete closure is required. Initial estimates have therefore been made to see if an open-loop system was feasible, which would significantly reduce the complexity of the LSS.

To calculate the mass of an open-loop system for this mission, basic human needs defined in the previous section have been used as a basis for food, water, oxygen and nitrogen masses estimations. Container masses, such as oxygen tanks or water bottles also had to be added. To reduce the concentration of $CO_2$ in the cabin and thus avoid intoxication of the astronauts, 1.75 kg per person per day of lithium hydroxide was also considered. The mass of all other equipment for hygiene, health, scientific experiments, safety, EVA suits, maintenance and repair of the spacecraft have been approximated at 4100 kg.

A redundancy of 50% was added for oxygen, nitrogen, lithium hydroxide and water reserves, to anticipate leaks or contamination. For food, a redundancy of 15% was considered.

In the end, the total mass of an open-loop configuration is 29.9 tons, the detail can be seen in appendix, Table VI. This mass being very high, it already seemed unreasonable to use such a configuration. By adding the volume constraints, the open-loop configuration has been eliminated.

In the following, the idea was to close as much as possible some loops, especially those of water and atmosphere.

## V. SYSTEMS DESIGN

### A. Atmosphere

One of the most important support systems necessary for humans is the atmosphere management. It deals with the oxygen generation and the carbon dioxide removal. 0.84 kg of oxygen is needed per human per day and 1 kg of carbon dioxide per person per day is exhaled. The air flow is regulated with ventilation systems. The pressurisation of the cabin is monitored. The atmosphere systems are also responsible for fire detection and suppression. Contamination is detected and avoided by filtering the air continuously. Technologies fulfilling all these processes are presented in the Table II. The systems in bold are the ones selected for the mission.

*1) $CO_2$ reduction and removal:*

A Sabatier reactor is used for the $CO_2$ reduction as on the ISS. Its weight is much lower than the one of the Bosch reactor. It uses a catalyst with two byproducts of the life support systems which are the carbon dioxide and the hydrogen. It produces methane and water in the water management (§V-B). Water is obviously reused. Methane can also be reused as a propellant. Carbon dioxide is also removed by molecular sieve 2-bed (2-BMS). The absorbing molecular sieve remove selectively the carbon dioxide from the air. On this ISS, molecular sieves 4-bed (4-BMS) are used. The mass of the 2-BMS is half of the 4-BMS and its efficiency is 90% against 66% for the 4-BMS. The only disadvantage of the 2-BMS is its technology readiness level (TLR) which is 2-3 against 8 for the 4-BMS. Development of the systems should improve the TLR in the coming years. The Air Polarized Concentration (APC) is like an Electrical Depolarized Concentrator (EDC) which does not require hydrogen for the carbon dioxide removal process. Basically, an anode and a cathode concentrate the carbon dioxide at their cavity. The outlet stream of the anode contains a high concentration of $CO_2$ unlike the outlet stream of the cathode. The first one is removed while the other one goes back to the cabin thanks to ventilation systems.

*2) $O_2$ generation:*

The Oxygen Generation System is directly linked to the Sabatier reactor. The solid polymer electrolyte of the SPWE (Solid Polymer Water Electrolysis) regulates the conduction of the protons during the electrolysis process. When saturated, this polymer becomes an excellent conductor. Artificial gills to collect oxygen from the plants was also considered. However, the cultivation of plants is not important enough to use this kind of technology since only one meal per week of fresh food will be provided to the crew (§V-C). It is still an interesting technology that could be considered for longer mission like going to Mars for instance.

*3) Ventilation and pressurisation:*

The natural flow of the air on Earth doesn't happen in space due to microgravity. Ventilation systems are necessary to avoid carbon dioxide suffocation as well as essential for the overall process of the Life Support Systems. Pressurisation is regulated in the different modules thanks to the Oxygen Generation System (OGS) and the nitrogen stored in high pressure tanks. The quantity of nitrogen is determined with the potential leaks that could happen in the whole spacecraft.

*4) Temperature and humidity control:*

A condensing heat exchanger (CHX) has been used in mostly all the manned space missions. Temperature control is needed for the comfort of the crew but also for the systems since they operate in a specific range of temperatures. Moisture could appear if the humidity is not well regulated and could damage the systems.

Table II
TECHNOLOGIES FOR ATMOSPHERE SUBSYSTEMS

| Function | Technologies |
|---|---|
| $CO_2$ removal | **Molecular sieve 2-bed (2-BMS)**<br>Molecular sieve 4-bed (4-BMS)<br>**Air polarized concentration (APC)**<br>Electromechanical depolarized concentrator (EDC)<br>Lithium hydroxide system<br>Potassium superoxide system<br>Solid amine system with water desorption (SAWD) |
| $CO_2$ reduction | Bosch reactor<br>**Sabatier reactor** |
| $O_2$ generation | Static Feed Water Electrolysis (SFWE)<br>**Solid Polymer Water Electrolysis (SPWE)**<br>Artificial gill<br>High pressure storage tanks<br>Cryogenic storage tanks<br>Oxygen candles |
| $N_2$ generation | Cryogenic gas storage<br>**High pressure gas storage**<br>Oxygen candles<br>Hydrazine subsystems<br>Amonia subsystems |
| Ventilation | **Air diffusers and intakes** |
| Temperature & humidity control | **Condensing heat exchanger (CHX)** |
| Trace contaminant control (TCC) | Particulate filters<br>Activated charcoal<br>Chemiabsorbant beds<br>Catalytic burners<br>Reactive bed plasma (RBP)<br>Super critical water oxidation (SCWO) |
| Fire detection & suppression | Obscuration smoke detector<br>Scattering smoke detector<br>condensation nuclei counter (CNC)<br>ionization smoke detector<br>UV/visible/IR flame detector<br>CO2 suppresion system<br>N2 fire suppression system<br>Halon fire suppression system |

*5) Trace Contaminant Control (TCC):*

Contamination is monitored continuously. Particulate filters first remove the biggest particles. In addition to it, expendable activated charcoal beds are used, like on the ISS, and appeared to be a reliable absorbent of contaminant particles. Regenerate activated charcoal is being studied which is promising for future long missions. While controlling the air contamination, the reactive bed plasma (RBP) can also destroy wastes.

*6) Fire detection and suppression:*

Fire is probably the scenario the astronauts are the most afraid of. Many detectors are set up in all the different modules (at least 2 per module). Nitrogen would be used to extinguish fire.

*7) Final Trade-off:*

The masses of the different atmosphere systems are based on the systems used on ISS. From a report discussing the use of ISS Life Support Systems for a Mars mission [4], the estimation of the number of spares was 3 for each systems on the ISS. Since this mission lasts less than one year, two redundancies were considered for each system. From the same report, the mass breakeven dates have been calculated and adapted to our mission. The breakeven date of a system is the ratio of the mass of the system and the input quantity mass (of this system) per day necessary for the whole crew. In other words, it is the time when the selected recycling systems will be profitable. It appeared that the breakeven dates of the Carbon Dioxide Removal Assembly (CDRA) and the Carbon Dioxide Reduction System (CDRS) were about 3 months and 11 months respectively, which is less than the duration of our mission (11 months). However, the breakeven date of the Oxygen Generator Systems (OGS) turned out to be 20 months which is nearly twice the duration of the mission. The open loop seemed to be an alternative for the oxygen generation. Nevertheless, using oxygen candles (Solid Fuel Oxygen Generation as Vika) required a mass of 2.3 tons and using high pressure storage tanks required a mass close to 9 tons. Comparing those masses with the mass of the OGS which is 1.5 tons (with 2 spares), it is still profitable to use the recycling oxygen system for our mission.

The total mass of the atmosphere systems including the spares turns out to be 3.3 tons and its volume 5.8 $m^3$.

## *B. Water*

The water subsystem should provide 4.17 kg of water per day per crew-member for crew use and consumption. It must be able to recycle almost 5.57 kg of water per day per crew-member [5]. The water provided shall meet current established water quality requirements, including those for microbial control [20].

*1) Candidate Technologies:*

The first technology mentioned was the current system on board the ISS, the Water Recovery System (WRS). Even though this system has proven itself and has a TRL 9, it was designed for a different mission. It was therefore relevant to consider other technologies in order to design a system that is as suitable as possible to this mission. The followed reasoning was therefore to adapt the WRS to this mission, by replacing some of the processes.

There are many technologies to generate or recycle water in space [23]. Several of them have been analyzed and compared in terms of mass, volume, productivity and other relevant points. For technologies with a TRL 5 or more, it was assumed that by the start of the mission, a higher TRL will be achieved. The results of this trade study are shown in Table III, in bold, the technologies chosen for this mission.

Table III
TECHNOLOGIES FOR WATER SUBSYSTEMS

| Function | Technologies |
|---|---|
| Water generation | **Sabatier reactor** |
| | Stored $H_2O$ |
| | **Water recovery from condensate** |
| Hygiene, potable water and condensate filtration | Multi-filtration beds (MF beds) |
| | **Reverse osmosis (RO)** |
| | Ultra-filtration |
| | Regenerable microbial check valves |
| | **Rotatory gas eparator** |
| | **Particulate filter** |
| | **Catalytic oxidation reactor** |
| Urine distillation | Vapor compression distillation (VCD) |
| | **Thermoelectric integrated membrane evaporator (TIMES)** |
| | Air evaporation system |
| Water quality and control | **Total organic carbon analyser** |
| | **Colorimetric water quality monitor kit** |
| | **Test kits** |
| | **Electronic nose** |
| | **Ion specific electrodes** |
| | **Conductivity probes** |
| | Advanced fiber-optic monitoring |

*2) Water generation:*

To generate water in space, the first solution is simply to use water stored and brought from Earth. This idea was quickly eliminated because it required too much volume and mass. The solution chosen was to keep the Sabatier reactor of the WRS which transforms $CO_2$ into water. This has the double advantage of reducing excess $CO_2$ in the cabin and creating water.

*3) Hygiene, potable water and condensate filtration:*

Concerning water filtration, the process of reverse osmosis (RO) has been selected. This process uses a membrane under pressure to separate relatively pure water from a less pure solution. Until now, multi-filtration (MF) beds were preferred because they were more reliable. However, recent flight experiments have proven the effectiveness of the RO and by the start of the mission, the TRL can be increased up to 8. Also, the resupply mass of RO is much lower than the one of MF beds, because they need to be replaced regularly [12].

*4) Urine distillation:*

The thermoelectric integrated membrane evaporator has been selected for urine distillation, instead of the Vapor compression distillation currently used in the WRS. It uses a thermoelectric heat pump to transfer heat from a water condenser to an evaporator. As the crew consists of only 3 members, it was assumed that the flow rates of the TIMES were sufficient for this mission. Moreover, this technology has a lower power consumption, is more compact and is gravity insensitive.

*5) Water quality and control:*

A strict control on the quality of the water must be carried out in order to maintain crew health. The maximum dose of chemical in water are stated in the Spacecraft Water Exposure Guidelines (SWEGs) for Potable Water [15]. To ensure the respect of these limits, many different control devices are used. The important parameters that need to be frequently measured are pH, ammonia content, total organic carbon, electrical conductivity and microbial concentration. Other parameters such as color or odor are checked occasionally.

To maintain the water quality, iodine or silver ions are added in combination with heat sterilization. Iodine could be passively adjusted by microbial check valves, as it was in the Space Shuttle [23].

*6) Final Trade-off:*

The water subsystem has one full redundancy, and a second redundancy for critical elements. The mass of the systems for generation of water, its filtration and urine treatment, is 2 011 kg, including redundancies and maintenance pieces. The break-even date compared to an open-loop system is 190 days.

The amount of water needed at the beginning of the mission also had to be considered. This water was stored in sophisticated, more resistant bottles to reduce the risk of leakage. The mass of these full bottles is about 72 kg, it provides water to the crew for 5 days.

Between 2013 and 2015, the WRS had an average potable water production rate of 12.7 kg per day [24]. It was assumed that the system modified for this mission could reach a similar production rate.

The current water recovery efficiency on ISS is 85%, it was assumed to reach 90% by 2033 with this new modified system. As human need 4.17 kg water per day and wastewater is 5.57 kg, it was not necessary to consider additional water to mitigate these losses.

Assuming 14.3 crew-hours per ton of water recycled for WRS maintenance [24], and assuming about 5.5 tons of total water recycled for the whole mission, the crew will have to devote 78.65 hours to maintenance of the water subsystem.

Two international standard payload racks are used to contain this subsystem [6]. Finally, the total mass of the water subsystem is 2 269 kg and it requires a volume of 3.2 $m^3$.

## C. Food

Mass and volume for food can be conveniently displayed in per person per day (or PPPD) values and the starting point for this study was Figure 3. The figure shows the different parts to consider for food: packaging, dry food mass water stored in food and beverages along with rehydration water and drinking water. The latter two parts regarding water is assumed to be covered by the water system and was not further examined. Regarding packaging, the literature [9] estimates a stowed mass of 0.5 kg

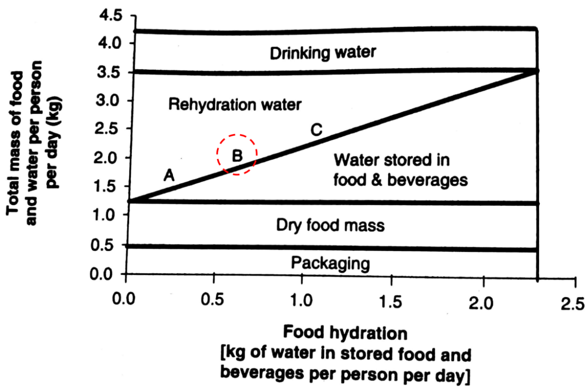



Figure 3. Guideline regarding food weights and hydration levels, where the circled area represents the approximate chosen level of hydration [9]

PPPD. A NASA article titled "Human Needs: Sustaining Life During Exploration" [16] on the other hand estimates that an astronaut on the ISS uses 0.36 kg PPPD of packaging. It was then reasonable to assume that 0.4 kg of packaging PPPD could be used. Due to the fact that the mission is in 2030 it was also deemed be reasonable that the packaging would have improved so that shelf life could be extended. This is necessary since food on the ISS is generally rated for up to one year, according to Matt Reynolds [11], which would have to be extended in order to be able to send food in advance for the mission. Extending the shelf life by another six months was then assumed possible, although the foods that would then meet this requirement might not be very exciting.

Food dry mass did not offer that much possibility for improvements, except for possibly something to pack more calories in less dry mass of food. It was thus decided to keep with the recommendation from the literature [9] in this case to try to keep a comfortable diet with as much variety as possible, meaning a dry mass of 0.7 kg PPPD. A similar approach was taken regarding the water stored in the food. The literature describes that levels similar to ISS, seen in Figure 3 as point C, is recommended for long duration missions. Point B in the figure was then chosen as reference for water content, meaning about 0.8 kg of water is stored in the food. This was to reduce mass while still not completely dehydrating the food which is seen as unrealistic. The total mass of a food packages PPPD was then 2 kg along with an assumed constant 0.008 $m^3$ food volume, as on the ISS. The water content, dry mass and packaging only adds up to 1.9 kg meaning 0.1 kg is included as a margin for variance. The total food mass was then divided into two equal parts of 1 ton and 4 $m^3$ each. One sent with the crew and one in advance.

Growing food instead of bringing it was also considered. However, this was quickly dismissed as the primary food source as the area requirements suggested in literature [9] was 15-20 $m^2$ per person. Growing food in space is also not yet fully reliable as a food source since it has not yet been thoroughly tested and proven. Although, to give the astronauts some fresh food, because resupplies are not possible, some fresh food was decided to be grown. It was decided that one meal per person per week was a good balance between space and what it provides. This meant that about 20 kg, a rough estimate excluding water, and 1 $m^3$ was dedicated to growing food.

### *D. Health*

Health risk for crews in space is not only the exposure to high-energy radiations as stated before but also physical and psychological effects on human body. Here physical and psychological effects and countermeasures are discussed.

#### *1) Physical Health:*

One of the main factors which influences the human body is microgravity. Microgravity affects the body in many ways. Table IV shows the effects on the human body in space and how to deal with these effects. Microgravity changes the circulation of body fluids and the structure of muscles and bones. Crews adapt to balance disorder, fluid shift, and cardiovascular deconditioning within days or weeks [21], but without high calorie food, medicine, and regular exercise, muscles and bones weaken and deteriorate. Studies have shown that astronauts experience up to 20% loss of muscle mass on spaceflights lasting 5 to 11 days [17] and the calcium balance between intake and excretion which is about zero on Earth decreases to about $-250$ mg/day during flight [18]. The loss of muscle and bone can be potentially dangerous if an astronaut must perform a strenuous emergency procedure upon reentry the Earth's gravitational field. To minimize the loss of muscle and bone, exercise is required. ISS has a treadmill, a bike and the Advanced

Resistive Exercise Device (ARED). These machines collectively weigh more than 1 800 kg and occupy about 24 $m^3$ within ISS. To reduce mass and space, new exercise equipment called Resistive Overload Combined with Kinetic Yo-Yo (ROCKY) has been developed [14]. ROCKY will accommodate aerobic activity and strength training, so it is not necessary to use several machines. ROCKY will weigh approximately 9 kg and take up about 0.028 $m^3$ of room. This mission will use ROCKY to reduce mass and volume.

Until recent years, eyesight deterioration caused by flattening of the globe and swelling of the optic nerve has been treated as a temporary problem, but recent study shows that eyesight deterioration may be permanent for some individuals [10]. To help meet astronaut needs on orbit, space anticipation glasses has been developed. These glasses have successfully decreased intracranial pressure which deteriorates eyesight, but have yet to be applied during spaceflight [1]. However, taking future development into account, these promising glasses were adopted to reduce eyesight deterioration.

Table IV
EFFECT ON HUMAN BODY AND HOW TO DEAL WITH IT

| Effect on human body | How to deal with it |
|---|---|
| Balance disorder | Adapt in a few days |
| Fluid shift | Adapt in a few days-a week |
| Cardiovascular deconditioning | Adapt in about one and a half month |
| Muscle atrophy | Exercise and high calorie food |
| Bone loss | Exercise and medicine |
| Eyesight deterioration | Space anticipation glasses |

#### 2) *Psychological Health:*

Psychological effects in space are also important to achieve the goals of space mission. Even if crews are good at dealing with severe environment, they may encounter some psychological problems. Stress caused by misunderstandings and impaired communications with other crews might influence performance. In addition, crews will undergo isolated and confined environments for a long time, so they might feel loneliness. Nutrition is also related to psychological effect. Lack of nutrition may cause physiological and cognitive decrements [19]. To reduce and prevent psychological problems, some psychological countermeasures were investigated. Selection and training of crews might represent efficient countermeasures to reduce the likelihood of performance decrements. Private meetings with family might be also helpful as the psychological countermeasure [13]. At the time of making schedule of crews, schedule analysis is needed which scrutinizes a balance between working hours and rest time.

Long-term space mission is considered to be stressful as mentioned above. However, traveling in space has many positive aspects as well, and for some it can be growth-enhancing. Some astronauts in space have reported transcendental experiences, religious insights, or a better sense of the unity of humankind as a result of viewing Earth below and the cosmos beyond [8]. This positive psychological effect may be consequential for this mission.

### *E. Hygiene*

This section focuses on the study of astronauts' clothing, other hygiene related items were not researched in depth and are therefore covered in the next section. The astronauts on board the ISS keep the same clothes for a few days and then put them aside. They regularly receive clean clothes from the ground. This is not an option for this mission. To reduce the number of clothes to bring on board, two solutions are combined. First of all, an integrated laundry system was considered. It could be developed by UMPQUA Research Company [7], which already did some work on laundry system for space. As the system will consume water and energy, it is best to limit its use. The idea then was to use clothes for a longer period. The solution was to use special material made of a combination of silver and hydrogen peroxide [2]. That would allow the clothes to stay microbe- and odor-free much longer. Considering 3 pants, 10 shirts, 2 pullovers, 12 underwear, 12 socks and 2 pairs of shoes, the total mass of clothes per crew-member was 9.5 kg for the whole mission.

### *F. Miscellaneous*

Many parts that are required for human space missions were not examined in depth in this project. For these factors the reference Figure 6, found in appendix was used and values were scaled appropriately. All masses and volumes for these systems can be found within Table V in the appendix. Brief motivations behind the choices for the parts that were not explored more in depth follows.

With the exception of food, all galley systems were directly taken from the lunar base column as the mission time is similar. However, freezers and microwave ovens along with dishwashers were excluded to save on weight. Regarding hygiene a slightly lighter washing faucet was assumed possible but personal hygiene kits and consumable hygiene supplies follow what was recommended. One toilet and similar waste collection supplies to a lunar mission was used along with 100 days of contingency fecal and urine bags to compensate for the possibility of toilet breakdowns. Dedicated personal storage was chosen similar to the shuttle, because of the relatively large space per person that already had been decided. Cleaning supplies such as vacuums, disposable wipes and trash bags was also the same as the shuttle but with slightly lighter vacuums. Other operational supplies, restraints/mobility aids, hand tools, test equipment and larger machine tools were picked similar to shuttle or lunar base. Some reductions were made because of assumed improved materials and low amount of experiments and since some systems, like the water system, had already accounted for maintenance equipment. Sleep restraints were assumed to use lighter materials than now and camera equipment was reduced because of low amount of use and assumed reduction in size. A reduced suite for all things medical along with consumables was taken into account to save space and mass. A mass of one ton with a volume of 3.5 $m^3$ was dedicated for rented experiments. This serves multiple purposes. It provides income and the astronauts with something to do on the journey, to avoid too much free time which could be harmful mentally. Collectively these systems who were not as deeply studied amount to an estimated mass of about two tons and a volume slightly over 7 $m^3$.

### G. EVA

As stated in subsection III-A, the number of EVAs, or extra vehicular activity, performed by the crew might be around 14. The EVA suits which were planned to be used are the ones of the Constellation program, the Constellation Space Suit System (CSSS). Event though the Constellation program has been cancelled, it has been assumed that similar suits are in development and, with the increased priority in exploring other celestial bodies, will be done for the planned launch date.

These suits use a regenerative life support system which currently lacks more details, but some data was found in literature [9]. The reason these suits were chosen was for their smaller mass of about 90 kg each and because they do not use consumables. This was of high priority since the stay at the asteroid will mostly consist of conducting many spacewalks.
Moreover, the CSSS consisted of two configurations:

- configuration 1: a light version of the suit, for special events such as launch and re-entry. It has to be used inside the spacecraft (IVA).
- configuration 2: the configuration used to practice proper EVAs

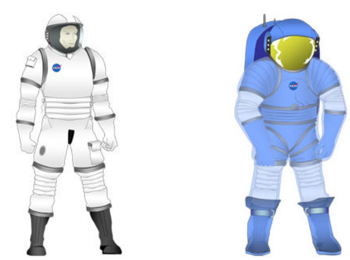


Figure 4. CSSS configuration 1 (left) and 2 (right)

Along with the suits the American SAFER, or Simplified Aid for Extravehicular Rescue, system was added as the astronauts will work in a zero gravity environment. Work aids and attachments to the spacesuits was also accounted for but tools for the operations was assumed to be sent with the cargo. The total mass for all EVA systems, accounting for one suit per crew member and one spare, was then 660 kg and it would take up about 2.9 $m^3$ of space. To be able to do EVAs an airlock was also needed. The airlock volume was chosen as 4.5 $m^3$ according to the recommendations from literature [9]. Since the airlock is unused for most of the journey it can provide storage for the spacesuits and other things such as different consumables most of the time.

### H. Final Design

Now the final design concerning the Human Aspects will be discussed. It was decided that partially closed loops would be used for the water subsystem and the air revitalization subsystem to reduce the mass of the spacecraft. The water subsystem recycles water with an estimated efficiency of 90%. Food is in open loop, as the mission is too short to consider an ecological life support system capable of hosting living plants and animals and that would cover food production. However, in order to reduce the mass of the manned spacecraft as much as possible, and thus respect the constraints of the launchers, a strategy of sending part of the LSS in advance has been adopted. The items concerned are half of the food, and some of miscellaneous objects such as hygiene supplies, trash bags, etc. These items will be sent in the first cargo ship carrying the equipment for the installation of the mining station.

The masses calculated for the manned spacecraft and the cargo ship sent in advance are respectively: 9.5 tons and 1.3 tons. Figure 5 shows the mass distribution of human aspects, considering the two spacecraft, with a total mass of 10.8 tons. The masses previously exposed do not take into account margins. An ESA document [3] was then used to estimate the margin that it was appropriate to consider. Since most items can be categorized as "Off-The-Shelf" items or "Off-The-Shelf" items requiring minor modifications, the margin was set to 10%. The new masses, including margins, for the manned spacecraft and the cargo ship sent in advance are respectively : 10.41 tons and 1.43 tons.

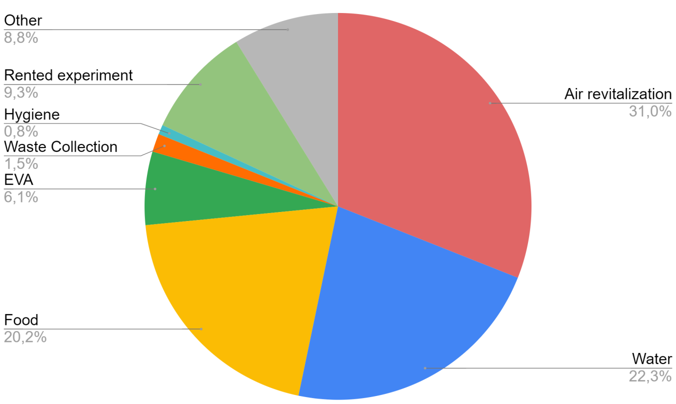



Figure 5. Mass distribution of human aspects parts

Concerning volumes, it is important to note that many assumptions have been made because little information is available. As uncertainties on actual size induce the risk of underestimating the volume needed, a margin of 15% was considered. Including this margin, the volume calculated for the manned spacecraft and the cargo ship sent in advance are respectively : 87 $m^3$ and 8.2 $m^3$

For the manned spacecraft, the maximum values, given by the "Space Vehicle" team, are 103 $m^3$ and 15.3 tons. The LSS presented in this paper fits in. Since the weight is including the hull of the vehicle the masses previously stated remained. However, since more volume was acquired the astronauts got the difference, 16 $m^3$ as extra crew space. With margins this meant that 65.5 $m^3$ was the total habitable volume, 21.8 $m^3$ per crew member. This also meant that the volume per astronaut ended up on the optimal curve mentioned in part III-B, which was preferred.

## VI. Off-nominal case

### A. Scenario

Fire, depressurization, and toxic gas may cause an off-nominal scenario related to human life during this mission. Especially, fire and depressurization may lead to most serious scenario and threaten human life. A spacecraft is a closed environment, so it is susceptible to the risk of fire damage. A hole in the structure could potentially result in sudden depressurization that would be fatal for the crew. Toxic gas can become significant if chemical compounds collect in a closed environment and risks increase as new materials are continuously added. In addition, serious solar event often accelerates ions to energies that can penetrate space suits and even spacecraft. Other than the above, new study shows that ISS is full of bacteria and fungi which are potentially dangerous [25]. However, a risk of bacteria and fungi is still not clear, so an analysis of that risk is needed.

A worst case is a situation that crews cannot stay on board and have to go back to Earth on the way to asteroid. To avoid that worst case, crews should have solutions against an off-nominal case in advance.

### B. Solutions

What is important is to avoid risks and have planned design measures or operational controls in case of an emergency situation. Fire detection and suppression are necessary to prevent and reduce the risk of fire. In case fire occurs, fire extinguishers are be mounted on board. Pressure sensors are used to monitor pressure. If depressurization happens, pressure sensor alarms danger of depressurization and crews need to specify where depressurization happens and fix the hole by using a sealant. Toxic gas is also monitored using a sensor. When toxic gas leaks, it is important to deal with gas leak quickly. Crews put on an oxygen mask and take refuge behind a closed hatch. After that, crews clean the air inside using a filter that removes toxic gas. In case of serious solar event, the space craft has a radiation shield to protect the human body. In addition, it is necessary to observe solar event from ground. If solar event becomes serious, crews don a space suit to better protect the body against extremes of radiation.

## VII. Crew

### A. Crew selection

Some brief considerations were made regarding the selection of the crew, their required skills and their training. Since the core of the mission is the setting up of the mining station on the asteroid, it requires a certain amount of physical strength. For this reason, it is preferable that the crew consists of at least two men. Men also have a higher tolerance to radiation. The crew will have to be made up of people aged around 40-45 years in 2030, again for radiation-related reasons.

It would be preferable for the entire crew to already have experience in space, such as a stay on board a space station of at least 3 months. In addition to the usual skills required for an astronaut, 3 specific skills have been identified. One of the astronauts must have extensive knowledge in the field of medicine. He or she must be able to react quickly in case of illness on board the spacecraft, without help from ground stations. Another must have a specialty in geology, to analyze the asteroid and decide the best places to mine. The last has to know about robotics.

### B. Crew's activities

Since human beings have been conditioned for thousands of years on a 24-hour day, it is important to maintain a similar cycle in space. The crew's workday will be from 6 a.m. to 9:30 p.m. based on ISS's workdays. Each crew member will have 1.5 consecutive days off, but not at the same time. They will have to exercise at least 2.5 hours a day. Activities during their working days will include daily conferences with ground, maintenance of machines, scientific experiments, regular public affair events, 3 meals per day, procedures review and leisure activities. A few weeks before arrival at the asteroid, their activities will focus on preparing for docking and EVAs. A few EVAs will also be planned during the transfer, to check the status of the spacecraft, and fix problems if necessary.

For safety reasons, during launch and return to Earth phases, the crew will be in the Dragon capsule wearing space suits.

## VIII. Conclusion

Since all the necessary systems to maintain and protect human life on the mission now have been considered, the task is complete. However, there were some difficulties along the way. During the work it was found difficult to know how deep the study should be done. In addition, time was needed before beginning the project due to the complexity of finding reference data to start from. It was found that the human aspects part of a space mission has a very wide scope. It includes everything from toilet paper to fire extinguishers and $CO_2$ removal to psychological health. The main parts of food, water, atmosphere and health was the start. Then as one part was completed the next most important area was decided and worked on. Finally, many parts were just scaled from existing systems in order to cover all that was found necessary. This approach seemed to work within the scope of this project and made the exchange of important data between groups easier. Most of the equipment used were also reasonable, in a development perspective, and not taken from science fiction. Thus, assuming that the solution would work in 2030 did not seem too far fetched.

# REFERENCES


[1] Arbeille P, Roumy J. “Adaptation of the left heart , cerebral and femoral arteries , and jugular and femoral veins during short- and long-term head-down tilt and spaceflights”, 2001

[2] D. Szondy, May 2017, https://newatlas.com/laundry-day-space/49490/

[3] ESA, 2012, "Margin philosophy for science assessment studies"

[4] Harry W. Jones, NASA Ames Research Center, Moffett Field, "Would Current International Space Station (ISS) Recycling Life Support Systems Save Mass on a Mars Transit ?", 47th International Conference on Environmental Systems, Charleston, South Carolina, 16-20 July 2017

[5] Harry W.Jones, "Would Current International Space Station (ISS) Recycling Life Support Systems Save Mass on a Mars Transit?", July 2017

[6] International Space Station User’s Guide, http://www.spaceref.com/iss/ops/ISS.User.Guide.R2.pdf

[7] J. Hsu, December 2011, https://www.space.com/13798-space-laundry-machine-microwaves.html

[8] Kanas, Nick, “Positive Effects of Space”, 2015

[9] Larson, Pranke, "Human Spaceflight: Mission Analysis and Design (Space Technology Series), First edition", McGraw-Hill College, 1999

[10] Mader TH, Gibson CR, Pass AF, et al. “Optic Disc Edema, Globe Flattening, Choroidal Folds, and Hyperopic Shifts Observed in Astronauts after Long-duration Space Flight”, 2011.06.021

[11] Matt Reynolds, "Nasa can’t send humans to Mars until it gets the food right", March 26, 2018, https://www.wired.co.uk/article/food-in-space-mars-iss-station-astronaut-eating

[12] M. Kayatin, J. Pruitt, M. Nur, K. Takada, L. Carter, "Upgrades to the International Space Station Water Recovery System", July 2017

[13] NASA, “Behavioral Health”, 2020-02-27, https://www.nasa.gov/content/behavioral-health

[14] NASA, “Exercise Device for Orion to Pack Powerful Punch”, 2020-02-27, https://www.nasa.gov/feature/exercise-device-for-orion-to-pack-powerful-punch

[15] NASA’s Human Health and Performance Directorate, "Spacecraft Water Exposure Guidelines (SWEGs)", July 2017

[16] NASA, "Human Needs: Sustaining Life During Exploration", April 16, 2007, https://www.nasa.gov/vision/earth/everydaylife/jamestown-needs-fs.html

[17] NASA, “Muscle Atrophy”, 2020-02-27, https://www.nasa.gov/pdf/64249main_ffs_factsheets_hbp _atrophy.pdf

[18] NASA, “Preventing Bone Loss in Space Flight with Prophylactic Use of Bisphosphonate”, 2020-02-27, https://www.nasa.gov/mission_pages/station/research/benefits/ bone_loss.html

[19] NASA, “The Human Body in Space”, 2020-02-27, https://www.nasa.gov/hrp/bodyinspace

[20] NASA’s Engineering Directorate, "Advanced Life Support Requirements Document", February 2003

[21] Nicogossian A.E, Lea & Febiger, "Space Physiology and Medicine", 1989

[22] Peter Eckart, "Space Technology Library, Space Flight Supports and Biospherics", 1994

[23] Peter Eckart, "Spaceflight Life Support And Biospherics", 1996

[24] R. Bagdigian, J. Dake, G. Gentry, M. Gault, "International Space Station Environmental Control and Life Support System Mass and Crewtime Utilization In Comparison to a Long Duration Human Space Exploration Mission", July 2015

[25] Sielaff AC, Urbaniak C, Mohan GBM, Stepanov VG, Tran Q, Wood JM, Minich J, McDonald D, Mayer T, Knight R, “Characterization of the total and viable bacterial and fungal communities associated with the International Space Station surfaces” Microbiome, 2019

[26] Space Faring - The Radiation Challenge, NASA’s Radiation Educator Guide, J. Rask, W. Vercoutere, B. J. Navarro, A. Krause, 2008

# APPENDIX

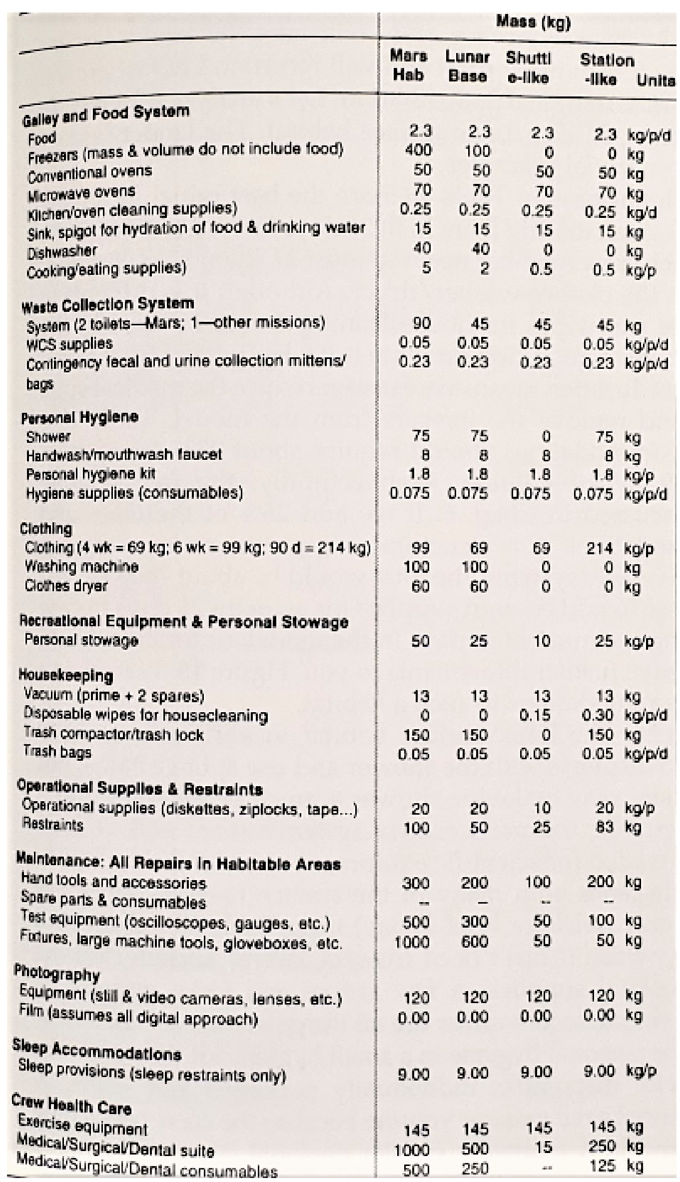
Table V
MASS AND VOLUME IN THIS MISSION

| | Mass (kg) | Volume ($m^3$) |
|---|---|---|
| **Food System** | | |
| Food** | 999 | 3996 |
| Kitchen cleaning supplies** | 41.625 | 0.2997 |
| Cooking/eating supplies | 6 | 0.0168 |
| Sink/spigot for hydrating food or drinking | 15 | 0.0135 |
| Conventional oven | 50 | 0.25 |
| Growing equipment | 20 | 1 |
| **Personal Hygiene** | | |
| Washing faucet | 6 | 0.01 |
| Personal hygiene kit | 5.4 | 0.015 |
| Hygiene supplies** | 37.5 | 0.75 |
| **Waste Collection System(WCS)** | | |
| Waste collection system | 45 | 2.15 |
| WCS supplies** | 25 | 0.65 |
| Contingency collection bags** | 34.5 | 0.12 |
| **Recreational Equipment&Personal stowage** | | |
| Personal stowage closet space | 30 | 0.57 |
| **Housekeeping** | | |
| Vacuum | 10 | 0.07 |
| Disposable wipes** | 75 | 0.5 |
| Trash bags** | 25 | 0.5 |
| **Operational Supplies&Restraints** | | |
| Operational supplies (tape, ziplock,etc.) | 15 | 0.003 |
| Restraints/Mobility aids | 25 | 0.3 |
| **Maintenance: All Repairs in Habitable Areas** | | |
| Hand tools and accessories*** | 40 | 0.13 |
| Test equipment (gauges, oscillosc., etc.) | 10 | 0.13 |
| Fixtures, large machine tools, etc.*** | 80 | 0.4 |
| **Photography** | | |
| Equipment (all digital) | 20 | 0.1 |
| **Sleep Accommodations** | | |
| Sleep restraints | 13.5 | 0.06 |
| **Crew Health Care** | | |
| Medical/surgical/dental suite | 250 | 1 |
| Exercise equipment | 18 | 0.18 |
| Personal stuff | 6 | 0.75 |
| Medical/surgical/dental consumables | 125 | 0.7 |
| **EVA System** | | |
| Tools and equipment (SAFER,workaid) | 300 | 0.5 |
| Space suits(3 primes and 1 spare) | 360 | 2.4 |
| Airlock | - | 4.5 |
| **Mission Experiment equipment** | | |
| Experiment equipment | 1000 | 3.5 |
| **Habitable Volume** | | |
| Required habitable volume | - | 45 |
| **Water System** | | |
| WRS | 2011 | 2.67 |
| TIMES | 170 | 0.23 |
| Total organic carbon analyser | 5 | 0.05 |
| Colorimetric Water Quality Monitor Kit | 5 | 0.05 |
| Test kits | 5 | 0.05 |
| Tanks | 9 | 0.09 |
| Initial water | 63.0 | - |
| Laundry system | 100 | 1 |
| Clothes | 2398 | 4.27 |
| **Atmosphere System** | | |
| Carbon Dioxide Removal Assembly | 423 | 0.78 |
| Carbon Dioxide Reduction System | 767 | 1.5 |
| Oxygen Generation System | 1474 | 3 |
| Trace Contaminant Control | 100 | 0.3 |
| Nitrogen Generation System | 403 | 0.2 |
| Oxygen loss | 173 | |
| **Safety System** | | |
| detection system | 2 | 0.002 |
| Safety masks | 5 | 0.025 |
| Fire extinguishers | 20 | 0.05 |
| Refill materials | 15 | 0.03 |
| Total | 9467 | 75.7 |
| Total with margins | 10413 | 87 |

** *half sent in advance*, *** *one third sent in advance*, *see Table VII*

Table VI
OPEN-LOOP MASSES

| | Total mass for the whole mission (kg) | With redundancies (kg) |
|---|---|---|
| Oxygen | 1012 | 1518 |
| Oxygen tanks | 7902 | 11853 |
| Nitrogen | 403 | 604 |
| Lithium hydroxide | 1748 | 2622 |
| Drinking and food preparation water | 2378 | 3566 |
| Urine flush water | 500 | 749 |
| Wash water | 1289 | 1933 |
| Water tanks | 417 | 625 |
| Food | 1998 | 4105 |
| Other | 4105 | 4105 |
| Total | 21750 | 29874 |



| | Mass (kg) | | | | |
|---|---|---|---|---|---|
| | Mars Hab | Lunar Base | Shuttle-like | Station-like | Units |
| **Galley and Food System** | | | | | |
| Food | 2.3 | 2.3 | 2.3 | 2.3 | kg/p/d |
| Freezers (mass & volume do not include food) | 400 | 100 | 0 | 0 | kg |
| Conventional ovens | 50 | 50 | 50 | 50 | kg |
| Microwave ovens | 70 | 70 | 70 | 70 | kg |
| Kitchen/oven cleaning supplies) | 0.25 | 0.25 | 0.25 | 0.25 | kg/d |
| Sink, spigot for hydration of food & drinking water | 15 | 15 | 15 | 15 | kg |
| Dishwasher | 40 | 40 | 0 | 0 | kg |
| Cooking/eating supplies) | 5 | 2 | 0.5 | 0.5 | kg/p |
| **Waste Collection System** | | | | | |
| System (2 toilets—Mars; 1—other missions) | 90 | 45 | 45 | 45 | kg |
| WCS supplies | 0.05 | 0.05 | 0.05 | 0.05 | kg/p/d |
| Contingency fecal and urine collection mittens/bags | 0.23 | 0.23 | 0.23 | 0.23 | kg/p/d |
| **Personal Hygiene** | | | | | |
| Shower | 75 | 75 | 0 | 75 | kg |
| Handwash/mouthwash faucet | 8 | 8 | 8 | 8 | kg |
| Personal hygiene kit | 1.8 | 1.8 | 1.8 | 1.8 | kg/p |
| Hygiene supplies (consumables) | 0.075 | 0.075 | 0.075 | 0.075 | kg/p/d |
| **Clothing** | | | | | |
| Clothing (4 wk = 69 kg; 6 wk = 99 kg; 90 d = 214 kg) | 99 | 69 | 69 | 214 | kg/p |
| Washing machine | 100 | 100 | 0 | 0 | kg |
| Clothes dryer | 60 | 60 | 0 | 0 | kg |
| **Recreational Equipment & Personal Stowage** | | | | | |
| Personal stowage | 50 | 25 | 10 | 25 | kg/p |
| **Housekeeping** | | | | | |
| Vacuum (prime + 2 spares) | 13 | 13 | 13 | 13 | kg |
| Disposable wipes for housecleaning | 0 | 0 | 0.15 | 0.30 | kg/p/d |
| Trash compactor/trash lock | 150 | 150 | 0 | 150 | kg |
| Trash bags | 0.05 | 0.05 | 0.05 | 0.05 | kg/p/d |
| **Operational Supplies & Restraints** | | | | | |
| Operational supplies (diskettes, ziplocks, tape...) | 20 | 20 | 10 | 20 | kg/p |
| Restraints | 100 | 50 | 25 | 83 | kg |
| **Maintenance: All Repairs in Habitable Areas** | | | | | |
| Hand tools and accessories | 300 | 200 | 100 | 200 | kg |
| Spare parts & consumables | -- | — | -- | -- | |
| Test equipment (oscilloscopes, gauges, etc.) | 500 | 300 | 50 | 100 | kg |
| Fixtures, large machine tools, gloveboxes, etc. | 1000 | 600 | 50 | 50 | kg |
| **Photography** | | | | | |
| Equipment (still & video cameras, lenses, etc.) | 120 | 120 | 120 | 120 | kg |
| Film (assumes all digital approach) | 0.00 | 0.00 | 0.00 | 0.00 | kg |
| **Sleep Accommodations** | | | | | |
| Sleep provisions (sleep restraints only) | 9.00 | 9.00 | 9.00 | 9.00 | kg/p |
| **Crew Health Care** | | | | | |
| Exercise equipment | 145 | 145 | 145 | 145 | kg |
| Medical/Surgical/Dental suite | 1000 | 500 | 15 | 250 | kg |
| Medical/Surgical/Dental consumables | 500 | 250 | -- | 125 | kg |

Figure 6. Hypothetical masses for different missions regarding crew

| | Volume ($m^3$) | | | | |
|---|---|---|---|---|---|
| | Mars Hab | Lunar Base | Shuttle -like | Station -like | Units |
| **Galley and Food System** | | | | | |
| Food | 0.0080 | 0.0080 | 0.0080 | 0.0080 | $m^3$/p/d |
| Freezers (mass & volume do not include food) | 2.00 | 0.50 | 0 | 0 | $m^3$ |
| Conventional ovens | 0.25 | 0.25 | 0.25 | 0.25 | $m^3$ |
| Microwave ovens | 0.30 | 0.30 | 0.30 | 0.30 | $m^3$ |
| Kitchen/oven cleaning supplies) | 0.0018 | 0.0018 | 0.0018 | 0.0018 | $m^3$/d |
| Sink, spigot for hydration of food & drinking water | 0.0135 | 0.0135 | 0.0135 | 0.0135 | $m^3$/ |
| Dishwasher | 0.56 | 0.56 | 0 | 0 | $m^3$/ |
| Cooking/eating supplies) | 0.014 | 0.0056 | 0.0014 | 0.0014 | $m^3$/p |
| **Waste Collection System** | | | | | |
| System (2 toilets—Mars; 1—other missions) | 4.36 | 2.15 | 2.18 | 2.18 | $m^3$ |
| WCS supplies | 0.0013 | 0.0013 | 0.0013 | 0.0013 | $m^3$/p/d |
| Contingency fecal and urine collection mittens/ bags | 0.0008 | 0.0008 | 0.0008 | 0.0003 | $m^3$/p/d |
| **Personal Hygiene** | | | | | |
| Shower | 1.41 | 1.41 | 0 | 1.41 | $m^3$ |
| Handwash/mouthwash faucet | 0.01 | 0.01 | 0.01 | 0.001 | $m^3$ |
| Personal hygiene kit | 0.005 | 0.005 | 0.005 | 0.005 | $m^3$/p |
| Hygiene supplies (consumables) | 0.0015 | 0.0015 | 0.0015 | 0.0015 | $m^3$/p/d |
| **Clothing** | | | | | |
| Clothing (4 wk = 69 kg; 6 wk = 99 kg; 90 d = 214 kg) | 0.336 | 0.224 | 0.224 | 0.720 | $m^3$/p |
| Washing machine | 0.75 | 0.75 | 0 | 0 | $m^3$ |
| Clothes dryer | 0.75 | 0.75 | 0 | 0 | $m^3$ |
| **Recreational Equipment & Personal Stowage** | | | | | |
| Personal stowage | 0.75 | 0.38 | 0.19 | 0.38 | $m^3$ |
| **Housekeeping** | | | | | |
| Vacuum (prime + 2 spares) | 0.07 | 0.07 | 0.07 | 0.07 | $m^3$ |
| Disposable wipes for housecleaning | 0 | 0 | 0.001 | 0.002 | $m^3$/p/d |
| Trash compactor/trash lock | 0.3 | 0.3 | 0 | 0.3 | $m^3$ |
| Trash bags | 0.001 | 0.001 | 0.001 | 0.001 | $m^3$/p/d |
| **Operational Supplies & Restraints** | | | | | |
| Operational supplies (diskettes, ziplocks, tape...) | 0.002 | 0.002 | 0.001 | 0.002 | $m^3$/p |
| Restraints | 0.54 | 0.27 | 0.135 | 0.54 | $m^3$/kg |
| **Maintenance: All Repairs in Habitable Areas** | | | | | |
| Hand tools and accessories | 1.00 | 0.66 | 0.33 | 0.66 | $m^3$ |
| Spare parts & consumables | -- | -- | -- | -- | -- |
| Test equipment (oscilloscopes, gauges, etc.) | 1.50 | 0.9 | 0.15 | 0.3 | $m^3$ |
| Fixtures, large machine tools, gloveboxes, etc. | 5.00 | 3.00 | 0.25 | 0.25 | $m^3$ |
| **Photography** | | | | | |
| Equipment (still & video cameras, lenses, etc.) | 0.50 | 0.50 | 0.50 | 0.50 | $m^3$ |
| Film (assumes all digital approach) | 0.00 | 0.00 | 0.00 | 0.00 | $m^3$ |
| **Sleep Accommodations** | | | | | |
| Sleep provisions (sleep restraints only) | 0.10 | 0.10 | 0.10 | 0.10 | $m^3$/p |
| **Crew Health Care** | | | | | |
| Exercise equipment | 0.19 | 0.19 | 0.19 | 0.19 | $m^3$ |
| Medical/Surgical/Dental suite | 4.00 | 2.00 | 0.25 | 1.00 | $m^3$ |
| Medical/Surgical/Dental consumables | 2.50 | 1.30 | -- | 0.64 | $m^3$ |

Figure 7. Hypothetical volumes for different missions regarding crew accommodations [9]

Table VII
MASS AND VOLUME FOR ITEMS SENT IN ADVANCE

| | Mass (kg) | Volume ($m^3$) |
|---|---|---|
| Food | 999 | 3996 |
| Kitchen cleaning supplies | 41.625 | 0.2997 |
| Hygiene supplies | 37.4625 | 0.74925 |
| WCS supplies | 24.975 | 0.64935 |
| Contingency collection bags (100 days) | 34.5 | 0.12 |
| Disposable wipes | 74.925 | 0.4995 |
| Trash bags | 24.975 | 0.4995 |
| Hand tools and accessories | 20 | 0.0667 |
| Fixtures, large machine tools, etc. | 40 | 0.2 |
| Total | 1302 | 7.1 |
| Total with margins | 1433 | 8.2 |